Project ID# eems075
Pillar(s): CAV

U.S. DEPARTMENT OF ENERGY
SMARTMOBILITY
Systems and Modeling for Accelerated Research in Transportation

General Microsimulation to Meso-Simulation Workflow

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2019 Vehicle Technologies Office Annual Merit Review, June 12, 2019

Argonne NATIONAL LABORATORY
INL Idaho National Laboratory
BERKELEY LAB
OAK RIDGE National Laboratory
NREL NATIONAL RENEWABLE ENERGY LABORATORY

OVERVIEW

- **Timeline**
  - **Project start date: Oct 1 2018**
  - **Project end date: Sept 30 2019**
  - **Percent complete: 50%**
- **Budget**
  - **Total project funding: $400K**
    - **100% DOE/VTO**
  - **Funding for FY 2019: $400K**
    - **LBL: $300K**
    - **ANL: $100K**
- **Barrier**
  - **How to develop mesoscopic traffic simulation for energy consumption evaluation for mixed traffic with different market penetration levels?**
  - **No field data with CAVs for meso-model calibration.**
  - **The Fundamental Diagram modeled from microscopic simulation with CAVs can be used for meso-simulation calibration.**
- **Collaboration**
  - **ANL**

OVERVIEW

- **Objectives:**
  - **Developing parameterized Fundamental Diagram (FD) that can cover a range of road geometry and a variety of traffic scenarios with different levels of market penetration of CAVs (LBNL); Implement I/O process for utilizing Parameterized FD (PFD) in meso-simulation (ANL)**
  - **Modeling Transportation Network Company (TNC) pick-up/drop-off with passenger cars and CAVs (Connected Automated Vehicles) in microscopic simulation**

RELEVANCE

- PFD (Parameterized Fundamental Diagram) Development:
  - It quantifies aggregated traffic behavior with difference function relationship: flow-density, speed-density and speed-flow
  - Parameterized FD (PFD) is critical for calibration of mesoscopic mixed traffic with manually driven and Connected Automated Vehicles (CAVs)
  - Modeling PFD can only use proper data from appropriate microscopic traffic simulation at different locations of a freeway corridor; no such real-world data with CAVs available
- Modeling TNC (such as Uber and Lyft) vehicle pickup/drop-off in microscopic level and their impact on arterial traffic
  - Necessary to quantify the pickup/drop-off behavior largely impact on urban arterial traffic
  - Those include different parking scenarios in different traffic situations

MILESTONES

Milestone Name/Description	Criteria	End Date	Type
• Q2: Determination if micro-simulation models can reasonably support a variety of traffic flow impact scenarios for use in meso-models (LBNL, ANL)	• Quantitative relationship between micro and meso-macro simulation	3/31/2019	Quarterly
• Q3: model for traffic flow impacts of TNC pick-up/drop-off activities (LBNL)	• A kinematic math model and implementation in micro simulation	6/30/2019	Quarterly
• Q4: Parameterized Fundamental Diagram for the specified road geometry and traffic scenarios (LBNL)	• Math model expression for such PFD	9/30/2019	Quarterly
• Q4: Documentation for FD modeling and other models developed (LBNL)	• Project Annual Report	9/30/2019	Quarterly
• Q4: report on the use of FD in meso and macroscopic simulation (ANL)	• Quantitative evaluation in meso-macro simulation	9/30/2019	Quarterly

APPROACH – PFD Modeling

- **Parameterized Fundamental Diagram (PFD) modeling and calibration**
  - **Using properly developed microscopic traffic simulation of a freeway corridor to generate simulation data at different critical locations and with different market penetration of CAVs**
  - **Developing math model for Parametrized FD (PFD)**
  - **Using simulation data to determine the coefficients of the PFD models**
  - **Compare the data fitting error to choose better PFD model**
  - **Applying the calibrated models for mesoscopic simulation calibration**

APPROACH – PFD Modeling

- **Modeling TNC manually and automatically driven vehicle on arterial corridor in urban area**
  - **Microscopic traffic simulation modeling/calibration and simulation for arterial corridor in urban area**
  - **Inject CAV car-following models in simulation**
  - **Developing microscopic TNC vehicle movement in microscopic simulation for different parking scenarios and at different locations**
  - **Such model is not available in any known commercially available simulation packages such as Aimsun, VISSIM, SUMO, and Paramics, etc.**

TECHNICAL ACCOMPLISHMENTS – PFD Modeling

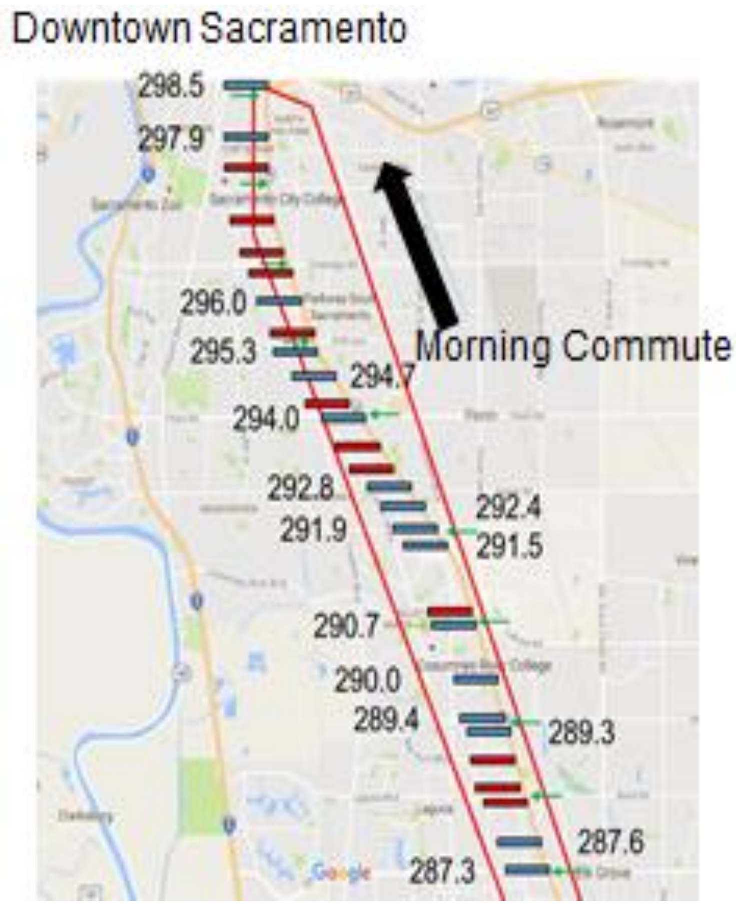
- **Math modeling of PFD:**
  - **Three PFD have been proposed and calibrated based on the Underwood Model**
  - **One new polynomial model has been created for 2-limb PFD**
  - **Original Underwood model: speed-density relationship; 4 PFD models developed based on it:**
    - **speed-density relationship**
    - **flow-density relationship**
    - **2-limb flow-density relationship based on the Underwood model**
    - **2-limb flow-density relationship with right limb as a 3rd polynomial**
  - **References:**

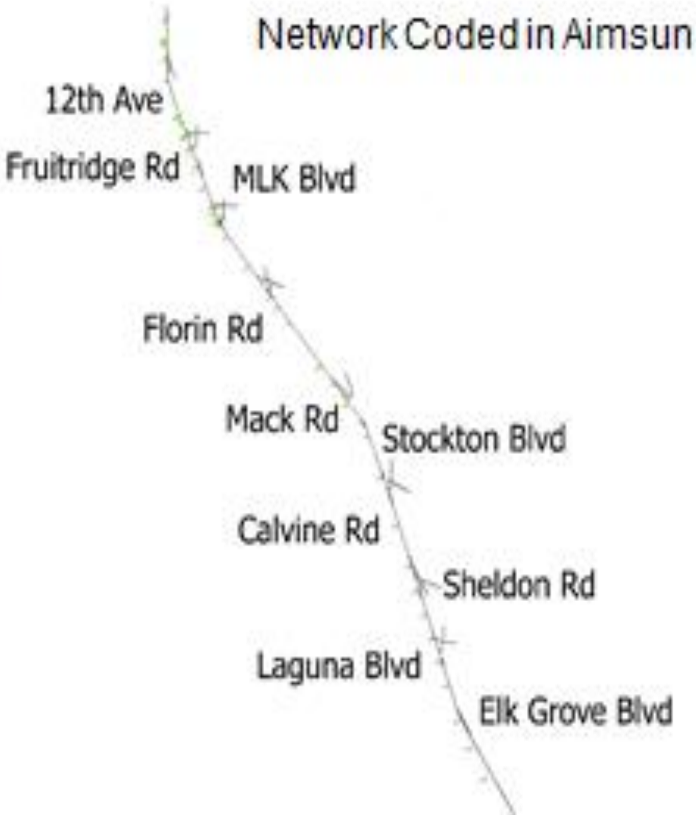
- R. T. Underwood, (1961). Speed, volume and density relationships, Quality and Theory of Traffic Flow, Yale Bureau of Highway Traffic, p141-88
- X. Y. Lu, P. Varaiya, and R. Horowitz, 2009, Fundamental Diagram modelling and analysis based NGSIM data, CD ROM of 12th IFAC Symposium on Control in Transportation Systems, Redondo Beach, CA, USA, September 2 – 4.

TECHNICAL ACCOMPLISHMENTS – PFD Modeling

- Data preparation for model coefficients determination
  - Freeway corridor microscopic simulation model: SR-99 NB between Elk Grove and SR-50 interchange in Aimsun
    - 13-mile urban corridor coded in Aimsun
    - 15 onramps and 11 off-ramps
    - 8-hour traffic demand from PeMS dataset
    - High traffic volume in AM Peak hours
    - Coordinated Ramp Metering in operation
  - Properly calibrated baseline traffic model based on PeMS data
  - With properly developed CAV model based on field test data in public traffic to capture dynamic interactions with other vehicles
  - Simulation time step 0.1 [s]; data saving every 30 [s]; data further aggregated to 2.5 [min] for model coefficient determination
  - The demands used are 20% more than that of the baseline traffic

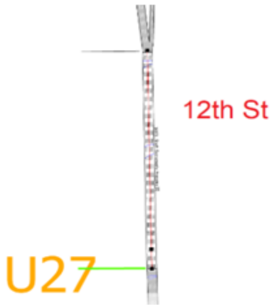
TECHNICAL ACCOMPLISHMENTS – PFD Modeling

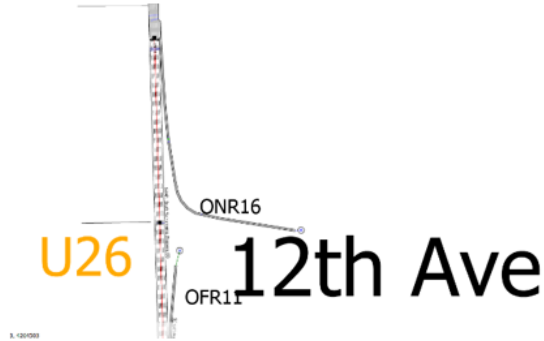


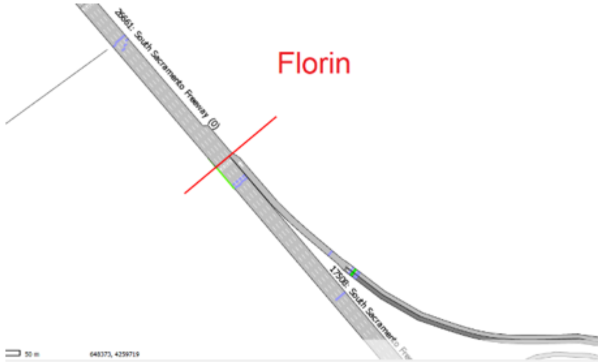


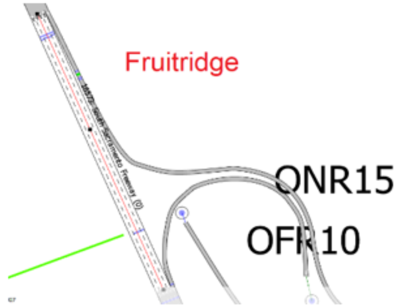
TECHNICAL ACCOMPLISHMENTS – PFD Modeling

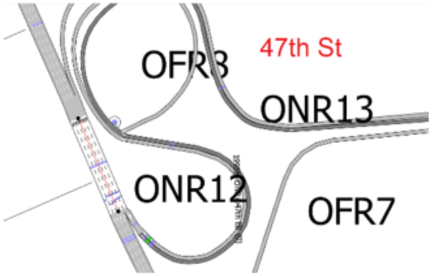
- **Model coefficients determined a 9 locations along the corridor to represent different road geometry and traffic demands:**





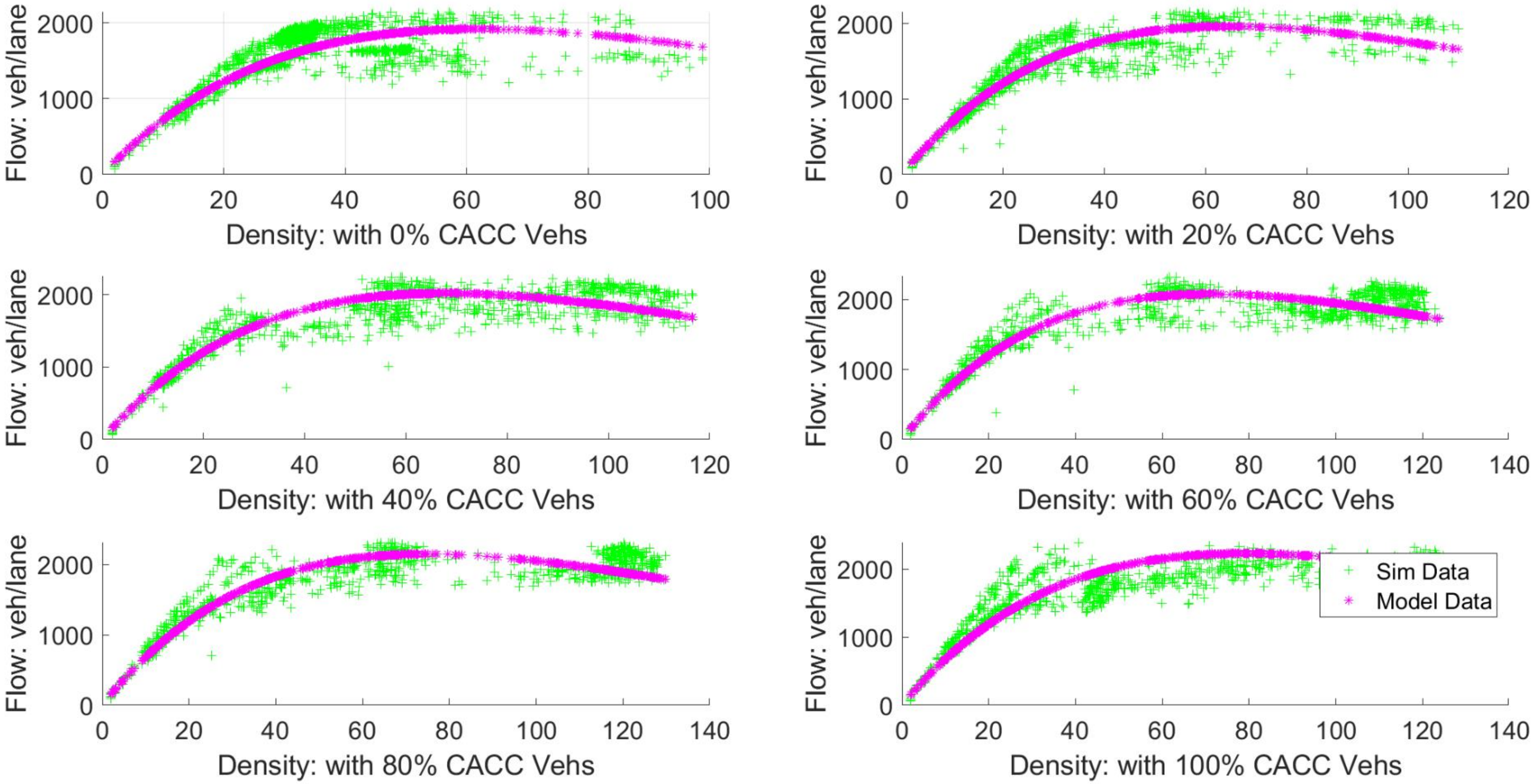






TECHNICAL ACCOMPLISHMENTS – PFD Modeling

- **Data Fitting: 1-Limb flow-density PFD based on Underwood model, plot of data fitting at bottleneck Florin WB**



TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **Comparison of RMSE of 3 flow-density PFD models at 9 locations**
- **Compared the RMSE (Root Mean Square Errors) of those 4 PFD models; the 1-Limb flow-density model has the smallest error so far**

Feature	Model 2	Model 3	Model 4
mainline upstream	2.896424	3.509257	3.104296
Weaving & Ln reduction	2.454432	3.091849	2.719658
offramp	3.36732	3.837351	3.472017
freeway split	2.237039	2.788488	2.557544
upstream of Calvin	1.874116	2.497038	2.371569
mainline onramp	2.022078	2.57428	2.411168
WB onramp section	2.645779	3.263253	2.874735
Node	3.36732	3.837351	3.472017
onramp	3.925805	4.598237	4.200451
Mean	**2.86452463**	**3.34173138**	**2.894114333**

TECHNICAL ACCOMPLISHMENTS – PFD Modeling

- **Next Step**
  - **Generate microscopic simulation data for mixed traffic with other demand level: 5% ~ 35% more than baseline (currently, only 20% more demand is used)**
  - **Determine the corresponding model coefficients**
  - **Investigate other possible PFD math models**
  - **Application of the PFD to mesoscopic simulation modeling**

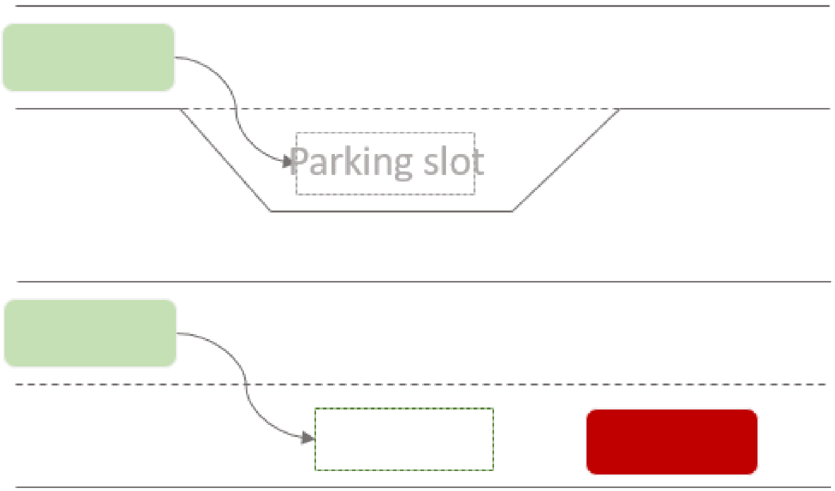
TECHNICAL ACCOMPLISHMENTS- TNC Pick-up Dropoff

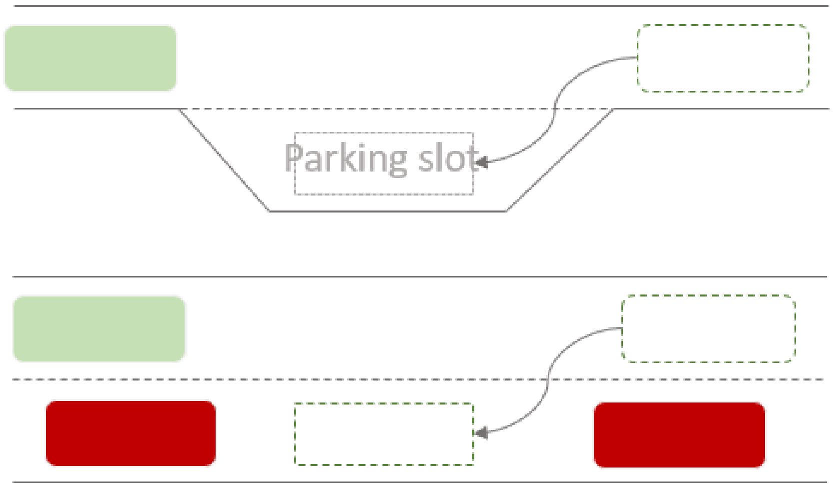
- **Modeling Transportation Network Company (TNC) pick-up/drop-off**
  - **Modeled an arterial corridor jointly with other project: 2-miles long on San Pablo at Berkeley City Center with several major crossing streets; with CAV car-following models**
  - **Determined microscopic 2D vehicle movement model for parking on curbside**
  - **Preliminarily determined TNC vehicle parking locations strategies**
  - **Coded the parking vehicle** (x, y) **movement as MicroSDK in Aimsun for different scenarios**

TECHNICAL ACCOMPLISHMENTS- TNC Pick-up Dropoff

- **Modes of parking maneuvers**
  - **Approaching**
  - **Waiting for parking spot**
  - **Parking**
  - **Holding (pick-up or drop-off)**
  - **Leaving**
- **Consider the two parking methods:**
  - **FP (Forward Parking): Regular lane changes into the parking space**
  - **PP (Parallel Parking): moving backward with yawing maneuver into the parking space**

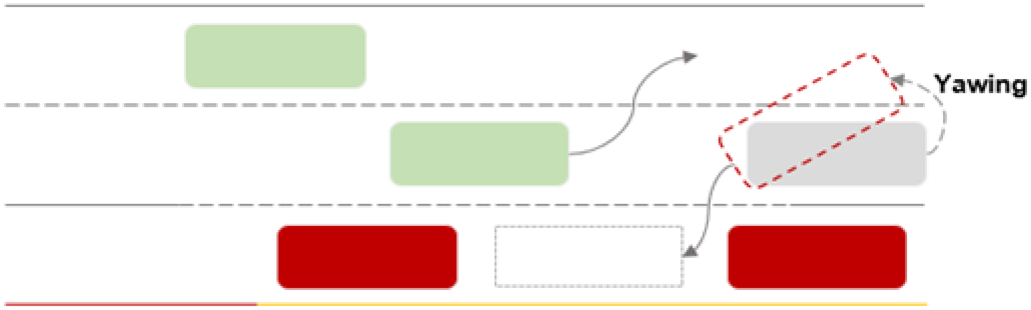
TECHNICAL ACCOMPLISHMENTS- TNC Pick-up Dropoff





a. **Forward Parking (FP)**
   - Same as the Lane Change maneuver

b. **Parallel Parking (PP)**
   - Moving backward to the parking slot



(partially or entirely) Lane block

TECHNICAL ACCOMPLISHMENTS- TNC Pick-up Dropoff

- **Network and Demand**
  - **Simple network (for straightforward experiment)**
  - **Microscopic traffic model of San Pablo Avenue (From Ashby avenue to Gilman St. 2 miles with 10 intersections)**
- **Experimental variables**
  - **Operation time (time for parking maneuver and dwell time)**
  - **Penetration Rate of TNC vehicles**
  - **Pick-up and Drop-off locations**
    - **Assumption: pick-up and drop-off occurs only on the predetermined parking spaces in the network**

TECHNICAL ACCOMPLISHMENTS- TNC Pick-up Dropoff

- **Next step:**
  - **Further baseline model calibration**
  - **Investigate the effects of TNC vehicles (manually & automatically driven) on arterial traffic for some specified scenarios**
  - **Develop a matching algorithm for delivery calls randomly generated in arterial roadways (e.g. Uber X)**
  - **Improve the matching algorithm for car-pooling (e.g. Uber pool)**
- **Sensitivity assess the impact of TNC vehicles' operation on the arterial traffic**
  - **Market share**
  - **Operation time**
  - **Passenger demands**

RESPONSES TO PREVIOUS YEARS REVIEWERS COMMENTS

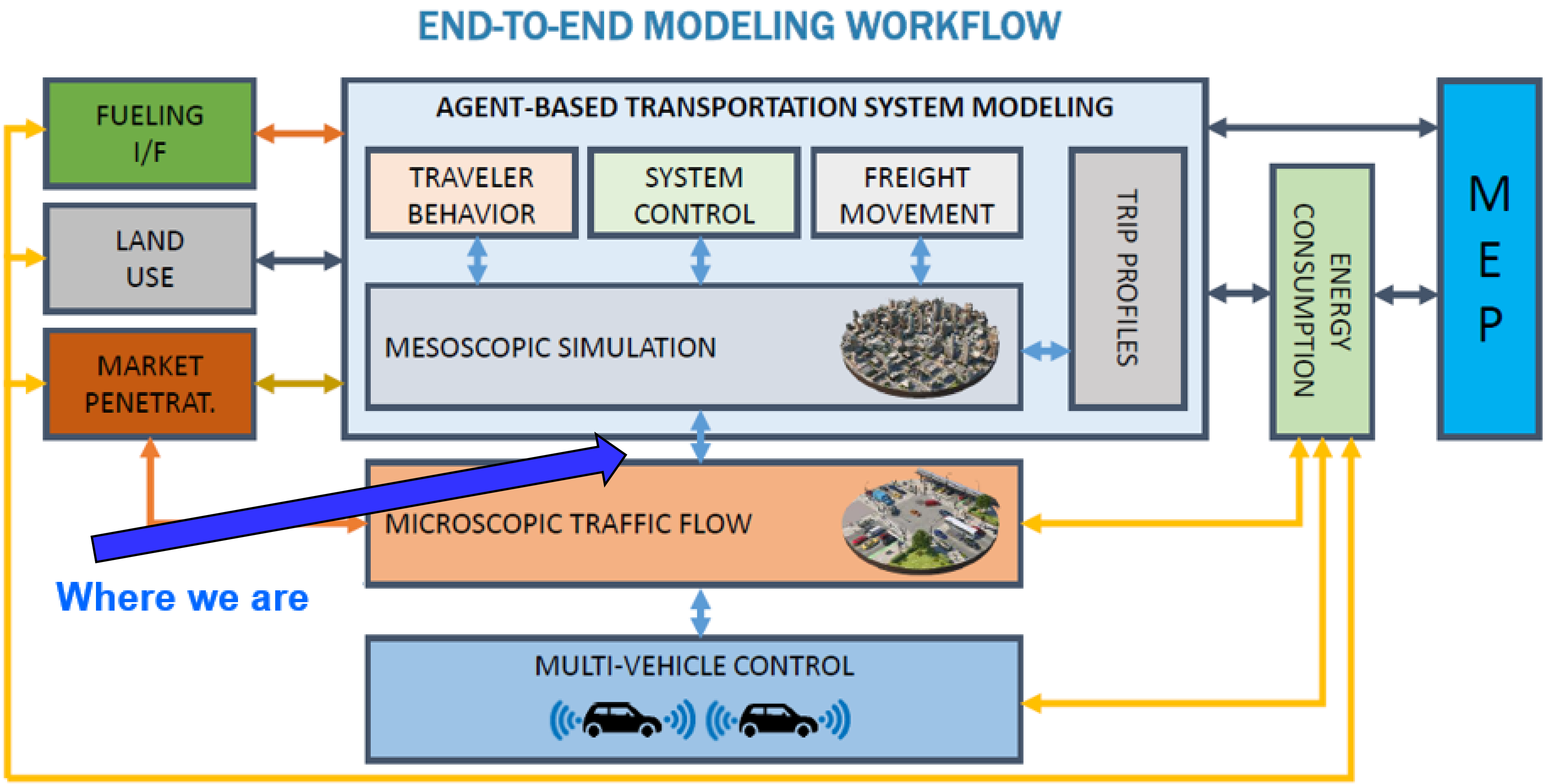
- **No reviewer comments. Project in first year.**

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS

- **ANL (Joshua Auld and Felipe August de Souza, ANL)**

- **Partner Projects on WorkFlow**
  - **EEMR031 – Microscopic simulation (Xiao-Yun Lu, LBNL)**
  - **EEMS078 - POLARIS MDS (Joshua Auld, ANL)**
  - **EEMS058 - ANL Workflow (Aymeric Rousseau, ANL)**
  - **EEMS011 - BEAM (Colin Sherpard, LBNL)**
  - **EEMS076 - RoadRunner to Micro (Dominik Karbowski, ANL)**

COLLABORATION AND COORDINATION WITH OTHER INSTITUTIONS – Where It Fits in the WORKFLOW



REMAINING CHALLENGES AND BARRIERS

- **Challenges:**
  - **What is the exhaustive list for PFD models (with respect to locations and traffic demands) for freeway corridors which are needed for mesoscopic mixed traffic simulation modeling**
  - **How to apply the PFD models determined by the mixed traffic simulation data of one freeway corridor to other freeway corridors and even to larger traffic networks**
  - **Model the TNC vehicle microscopic behavior which commercially available simulation package (Aimsun, VISSIM) does not have function to use**

PROPOSED FUTURE RESEARCH

- PFD (Parameterized Fundamental Diagram):
  - PFD modeling for arterial corridors
  - Find out what is the exhaust list for PFD models for arterial
  - How to apply the PFD so developed to mesoscopic simulation
  - PFD for network traffic with both freeway and arterial corridors
  - Any relationship between the two types of PFDs: freeway and arterial; how to quantify?
- Modeling TNC pick-up/drop-off vehicle effects on arterial traffic
  - More systematic consideration of TNC traffic in a network level
  - Modeling and simulating TNC freight vehicles: parcel pickup & drop-off effect on urban traffic in microscopic level
- Future research will be subjected to the availability of funding

SUMMARY SLIDE

- Generated microscopic mixed traffic (manually driven vehicles & CAVs) simulation data with 20% more demands over baseline traffic and different penetration levels of CAVs from SR99 NB model
- Created PFD models based Underwood speed-density model
  - 1-Limb speed-density model
  - 1-Limb flow-density model
  - 2-Limb flow-density model
- Created 2-Limb PFD with right limb as 3rd polynomial model
- Determined the coefficients for those 4 models; all 2-limd models with fixed critical density as 28 [veh/Ln.Mile]
- Those models can support meso-simulation in model calibration
- Preliminarily modeled arterial corridor with TNC vehicles and developed some microscopic TNC vehicle movement model for different parking scenarios in Aimsun

QUESTIONS?

TECHNICAL BACK-UP SLIDES

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **Math modeling of PFD:**
  - **Three PFD have been proposed and calibrated based on the Underwood Model**
  - **One new polynomial model has been created for 2-limb PFD**
  - **Original Underwood model: speed-density relationship:**

$$v(\rho) = \exp(w_1 + w_3\rho)$$

$v -$ distance mean speed [mph]

$\rho -$ density, number of vehicles per-mile

$(w_1, w_2) -$ unknown coefficients to be determined by data

  - **References:**

– R. T. Underwood, (1961). Speed, volume and density relationships, Quality and Theory of Traffic Flow, Yale Bureau of Highway Traffic, p141-88

– X. Y. Lu, P. Varaiya, and R. Horowitz, 2009, Fundamental Diagram modelling and analysis based NGSIM data, CD ROM of 12th IFAC Symposium on Control in Transportation Systems, Redondo Beach, CA, USA, September 2 – 4.

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **PFD Model 1: speed-density relationship based on the Underwood model**

$$v(\rho) = \exp\left(w_1 + w_3\kappa + \left(w_2 + w_4\kappa\right)\rho\right)$$

$v -$ distance mean speed [mph]

$\kappa -$ CAV markete penetration level in percentage, $0 \le \kappa \le 1$

$\left(w_1, w_2, w_3, w_4\right) -$ coeffcients to be determined by data

- **PFD Model 2: flow-density relationship based on the Underwood model**

$$q(\rho) = \rho \cdot \exp\left(w_1 + w_3\kappa + \left(w_2 + w_4\kappa\right)\rho\right)$$

$q -$ flow, number of vehicles passed at a location per-hour-per-lane

$\left(w_1, w_2, w_3, w_4\right) -$ coeffcients to be determined by data

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **PFD Model 3: two-limb flow-density relationship based on the Underwood model**

$$q(\rho) = \begin{cases} V_f \rho, & \rho(\kappa) \le \rho_c(\kappa) \\ \rho \cdot \exp\left(w_1 + w_3\kappa + \left(w_2 + w_4\kappa\right)\rho\right), & \rho(\kappa) > \rho_c(\kappa) \end{cases}$$

  - **The left limb represents the free-flow part, which is a straight line proportional to the density**
  - **In principal, $\rho_c(\kappa)$ depends on market penetration level, but our calibration showed that this dependence is small and could be ignored at this stage; $\rho_c(\kappa) = 28$ is used in model calibration**

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **PFD Model 4: two-limb flow-density relationship with right limb as a 3rd polynomial**

$$q(\rho)=\begin{cases} V_f\rho, & \rho(\kappa)\le\rho_c(\kappa) \\ w_1+\kappa w_2+(w_3+\kappa w_4)\rho+(w_5+\kappa w_6)\rho^2+(w_7+\kappa w_8)\rho^3, & \rho(\kappa)>\rho_c(\kappa) \end{cases}$$

  - **There are 8 unknown parameters to be determined with data**
  - **The left limb represents the free-flow part, which is a straight line proportional to the density**
  - **In principal, $\rho_c(\kappa)$ depends on market penetration level, but our calibration shoed that this dependence is small and could be ignored at this stage; $\rho_c(\kappa)=28$ is used in model calibration**

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **Modeling Results**
  - **Model 1: 1-Limb speed-density PFD based on Underwood model, the calibrated coefficients**

w1	w2	w3	w4	Feature	Onramp, offramp name & ID
4.33599	-0.014158	-0.017496	0.004289	mainline upstream	up Florin WB;
4.329973	0.004325	-0.01799	0.00499	Onrampo weaving section & lane reduction	47th St, EB onramp ID 16785 & offramp ID 16565
4.3172	-0.07221	-0.017376	0.004634	offramp	12th Ave; 16833
4.325519	-0.02296	-0.017911	0.005108	freeway split	SR99 and SR50 ooframp split
4.269999	0.056901	-0.016484	0.003113	upstream of Calvin	Mainline, bottleneck
4.282642	0.023259	-0.016814	0.003752	mainline onramp section	Calvin Onramp, bottleneck
4.331372	0.010379	-0.017567	0.004296	WB onramp section	47th St, WB onramp ID 16731
4.3172	-0.07221	-0.017376	0.004634	Node	Flroin Onramo WB; 16571
4.294444	-0.176749	-0.016954	0.005375	onramp	12th Ave; 16833

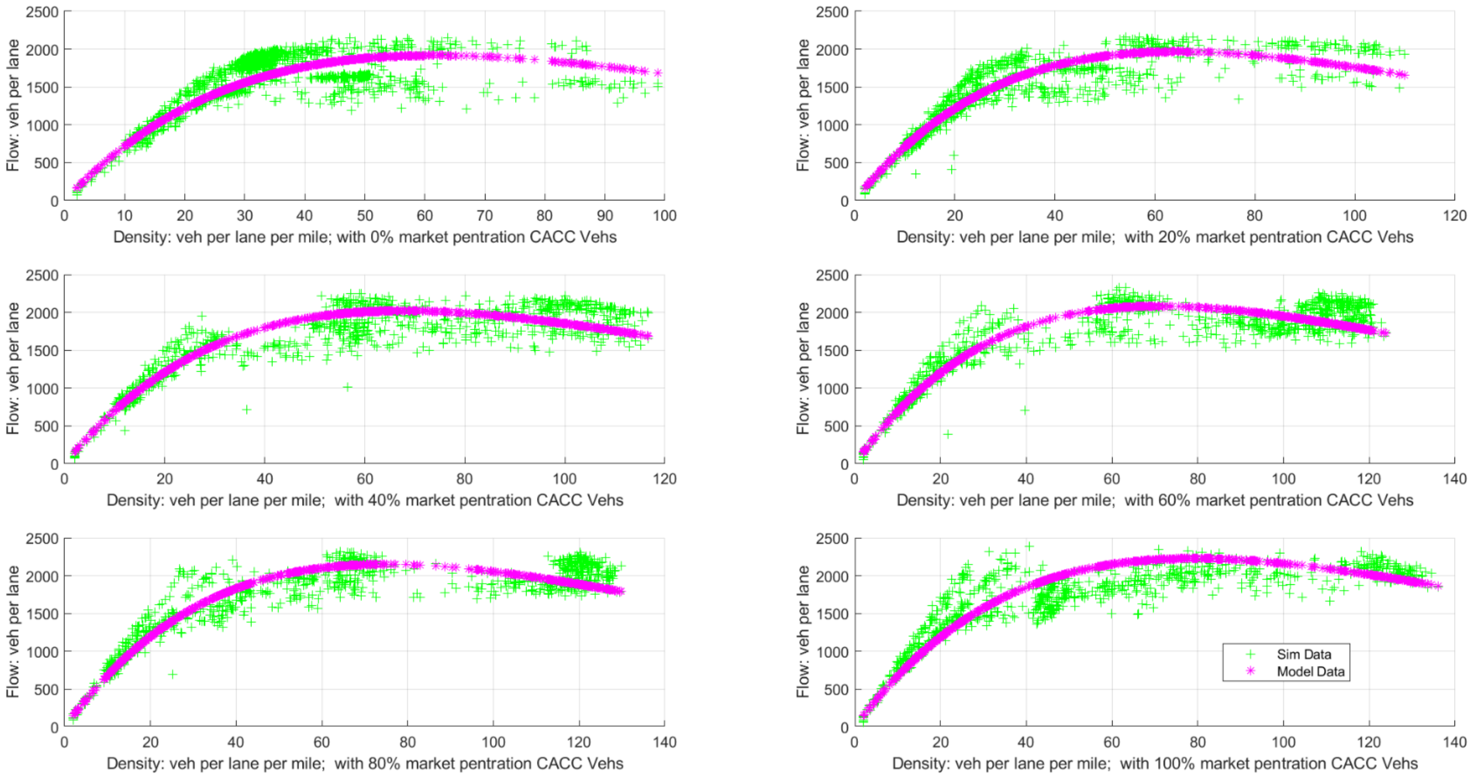
TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **Model 2: 1-Limb flow-density PFD based on Underwood model, the calibrated coefficients**

w1	w2	w3	w4	Feature	Locations
4.436414	-0.098583	-0.016203	0.003556	mainline upstream	up Florin WB
4.439163	-0.122457	-0.017135	0.004574	Weaving & Ln reduction	47th St, EB onramp
4.481578	-0.140879	-0.016526	0.004091	offramp	12th Ave
4.436462	-0.126858	-0.017048	0.004493	freeway split	SR99 and SR50 split
4.412587	-0.111317	-0.017118	0.004582	upstream of Calvin	Mainline Bottleneck
4.42471	-0.130688	-0.017084	0.00467	mainline onramp	Calvin Onramp, bottleneck
4.428239	-0.112219	-0.016713	0.004207	WB onramp section	47th St, WB onramp
4.481578	-0.140879	-0.016526	0.004091	Node	Flroin Onramo WB
4.432746	-0.190121	-0.015858	0.004399	onramp	12th Ave

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **Model 2: 1-Limb flow-density PFD based on Underwood model, plot of data fitting at bottleneck Florin WB**



TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **Model 3: 2-Limb flow-density PFD based on the Underwood model, the calibrated coefficients**

w1	w2	w3	w4	Feature	Locations
4.465379	-0.319349	-0.016649	0.006028	mainline upstream	up Florin WB
4.457343	-0.314708	-0.017468	0.006818	Weaving & Ln reduction	47th St, EB onramp
4.500078	-0.404735	-0.016771	0.006829	offramp	12th Ave
4.467079	-0.325812	-0.017557	0.006925	freeway split	SR99 and SR50 split
4.451462	-0.295926	-0.01758	0.006683	upstream of Calvin	Mainline Bottleneck
4.454638	-0.304554	-0.0175	0.00673	mainline onramp	Calvin Onramp, bottleneck
4.463017	-0.331347	-0.017271	0.006786	WB onramp section	47th St, WB onramp
4.500078	-0.404735	-0.016771	0.006829	Node	Flroin Onramo WB
4.465229	-0.410345	-0.016274	0.006796	onramp	12th Ave

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- Model 4: 2-Limb flow-density PFD based on 3rd order polynomial model, the calibrated coefficients

w1	w2	w3	w4	w5	w6	w7	w8	Feature	Locations
1715.806146	-992.968322	0.587965	36.861872	0.011884	-0.358004	-0.000065	0.00112	mainline upstream	up Florin WB
1898.433066	-455.762301	-9.820365	14.978564	0.149291	0.071767	-0.000755	0.000115	Weaving & Ln reduction	47th St, EB onramp
1846.948268	-1511.88253	-3.569289	51.087556	0.074794	-0.465732	-0.000418	0.001397	offramp	12th Ave
1738.438663	-718.397659	-1.541726	23.373475	0.040708	-0.150552	-0.000342	0.000347	freeway split	SR99 and SR50 split
1228.014555	-145.806027	21.138468	5.365898	-0.253904	0.253179	0.00067	-0.001164	upstream of Calvin	Mainline Bottleneck
1438.455501	-429.690567	11.97171	8.304154	-0.135141	0.064032	0.00024	-0.000418	mainline onramp	Calvin Onramp, bottleneck
1687.930994	-967.78252	3.404508	34.147373	-0.086432	-0.268983	0.000593	0.000519	WB onramp section	47th St, WB onramp
1846.948268	-1511.88253	-3.569289	51.087556	0.074794	-0.465732	-0.000418	0.001397	Node	Flroin Onramo WB
1826.469337	-1877.37819	-1.444474	60.991889	0.032636	-0.536917	-0.000166	0.001491	onramp	12th Ave

TECHNICAL ACCOMPLISHMENTS AND PROGRESS

- **Model 4: : 2-Limb flow-density PFD based on 3rd order polynomial model, plot of data fitting at bottleneck Florin WB**